Applied Surface Science 357 (2015) 1313–1318

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Enhanced field emission from nanosecond laser based surface micro-structured stainless steel

A.K. Singh[a,*], Deodatta Shinde[b], Mahendra A. More[b], Sucharita Sinha[a]

[a] Laser & Plasma Technology Division, Bhabha Atomic Research Centre, Mumbai 400085<p/ostalC>, India
[b] Department of Physics, Savitribai Phule Pune University, Pune 411007, India

ARTICLE INFO

Article history:
Received 12 June 2015
Received in revised form
29 September 2015
Accepted 29 September 2015
Available online 3 October 2015

Keywords:
Micro-structuring
Laser irradiation
Field emission
Field enhancement

ABSTRACT

This paper presents results of field emission study of laser based surface micro-structured stainless steel (SS). Surface micro-structuring of SS samples has been performed by direct irradiation of sample surface with a frequency doubled Nd:YAG nanosecond (ns) laser in atmospheric ambience. Laser treated samples have been characterized in terms of their surface morphology, elemental composition and field emission properties. Our results reveal formation of micro-protrusions of varying height and tip diameter depending on incident laser fluence. Within the laser irradiated spot, regions near periphery showed formation of micro-protrusions with number density as high as 4.5×10^7 protrusions/cm^2. Such laser micro-structured samples have shown much lower turn on electric field (7.5 V/μm) in comparison to untreated SS samples. Macroscopic field enhancement factor (γ_c) and macroscopic pre-exponential correction factor which is a provisional measure of area efficiency of emission of the laser modified sample surface were estimated to be 585 and 2.72×10^{-10}, respectively. Emission current stability measurements for a preset level of 4 μA showed good performance when tested over a period ~140 min.

1. Introduction

Laser induced surface modification particularly aimed at altering specific surface properties can often lead to improved performance in selected applications. For example, formation of surface pores on sensing materials lead to enhancement in sensitivity of sensors while pores on the surface of corrosion protective coatings are undesirable. Some other examples of surface modifications that are desired based on specific applications being targeted are: surface micro-structuring of silicon leading to enhancement in absorptivity of silicon and hence efficiency of solar cells [1], surface texturing of biomedical materials such as Ti6Al4V before implantation in human body to improve integration of implant with surrounding body tissues [2], wettability control of material surfaces by ultra-short pulsed laser induced surface modifications [3], and pulsed laser induced generation of an array of self-aligned micro/nano tips on cathode surface to enhance cold field electron emission property of these cathodes [4–6].

Cold field emitters offer numerous advantages over conventional thermionic emitters. These include, low power consumption, high brightness (for single tip emitter typically ~10^2–10^3 times higher than thermionic emitters) [7], low energy spread of emitted electrons [7], low operating temperature, rapid switching capability (up to few GHz) [8,9] and longer cathode life time. Development of cold field emission cathodes operating at low voltage and delivering high current density is of interest for several applications such as flat panel display [10], radio and micro wave generation and amplification [8,11], electron beam sources in free electron lasers[12] and scanning electron microscopes (SEMs). Large area cold field emitter arrays have been reported with high electron beam emittance [9]. A major advantage associated with large area field emitters is that they can withstand larger emission current in comparison to their single tip counterparts without damage. Therefore, for applications which require large current along with high current density large area field emitters are preferred. Formation of an array of micro-tips or protrusions on cathode surface with each tip serving as a field emitter can provide a means to enhance field emission capability.

Numerous methods have been employed to develop micro-protrusions on solid surfaces such as spindt technique [13], electrochemical etching [14], electron beam lithography [15] and films deposition techniques [16]. However, generation of surface micro/nano protrusions on target surface achieved by direct laser irradiation based technique offers several notable advantages. In

* Corresponding author.
E-mail address: anilks@barc.gov.in (A.K. Singh).

http://dx.doi.org/10.1016/j.apsusc.2015.09.244
0169-4332/

addition to being a single step and a clean process (as it does not involve use of any chemical) laser based surface treatment also provides process flexibility through easy control of process parameters.

In this work, being reported surface micro-structuring of stainless steel sample has been performed using nanosecond pulsed Nd:YAG laser irradiation. Surface modified stainless steel samples have been investigated in terms of their surface morphology, change in chemical composition on laser irradiation and field emission properties. Field emission study has been carried out using a planar diode configuration. Field emission parameters, such as turn on field, macroscopic field enhancement factor, slope correction factor, pre exponential correction factor have been estimated using emission current density versus applied field characteristics. Stability of the field emission current has also been tested for a time period of ~140 min.

2. Experiment

In this work, surfaces of polished stainless steel pieces were irradiated in air by nanosecond laser pulses resulting in generation of self-assembled surface micro-structures over a laser treated area of ~17 mm^2. For laser surface micro-structuring a frequency doubled Nd:YAG laser operating at a wavelength of 532 nm, pulse repetition rate of 10 Hz and delivering pulses of 6 ns pulse duration (FWHM) has been used. Sample targets were typically irradiated with ~6000 laser pulses at a laser fluence of ~0.7 J/cm^2. Surface micro-structures generated on the irradiated spot were observed under a scanning electron microscope (SEM) and change in elemental composition of the modified surface was analyzed by energy dispersive spectroscopy (EDS). Estimate of height of the developed micro-protrusions and details of surface profile of the irradiated target were traced using a surface profiler [Make: Hobson Taylor, Model: Form Tally Surf Series 2.0].

Field emission properties of the laser treated sample were investigated in a planar diode configuration under ultra-high vacuum condition (pressure ~10^{-8} mbar). For these measurements surface micro-structured stainless steel sample serving as the cathode was held parallel to a semi-transparent anode screen. The semi-transparent anode facilitates visual imaging of the field emission spot on the anode using a digital camera. During the field emission characterization, separation between cathode surface and anode screen was kept fixed at 0.5 mm and external high voltage was applied using Spellman high voltage DC power supply. Emission current was estimated by measuring voltage drop across a standard 102.5 kΩ resistance. To study field emission current stability over an extended period of time voltage drop across the resistance was recorded using a data logger which was set to record voltage value at every 10 s. These voltage data were then used to estimate emission current.

3. Results and discussion

Fig. 1(a–d) depicts SEM images of surface micro-structures of a laser irradiated spot at different magnification levels. Fig. 1a reveals formation of micro protrusions within the entire laser irradiated spot. Different sections of the laser treated spot contain micro-protrusions of varying height and diameter. High density of surface micro-protrusions shown in Fig. 1c and d refer to regions marked by a rectangle within the laser treated spot shown in Fig. 1a and c, respectively. Average density of micro-protrusions and their mean tip diameter estimated within the rectangular region in Fig. 1c are ~4.5×10^7 protrusions/cm^2 and 1.2 μm, respectively.

To get an estimate of height of the generated surface micro-protrusions 3-dimensional surface profiling of the laser modified sample has been performed using a surface profiler. A typical surface profile scan of the laser treated spot has been shown in

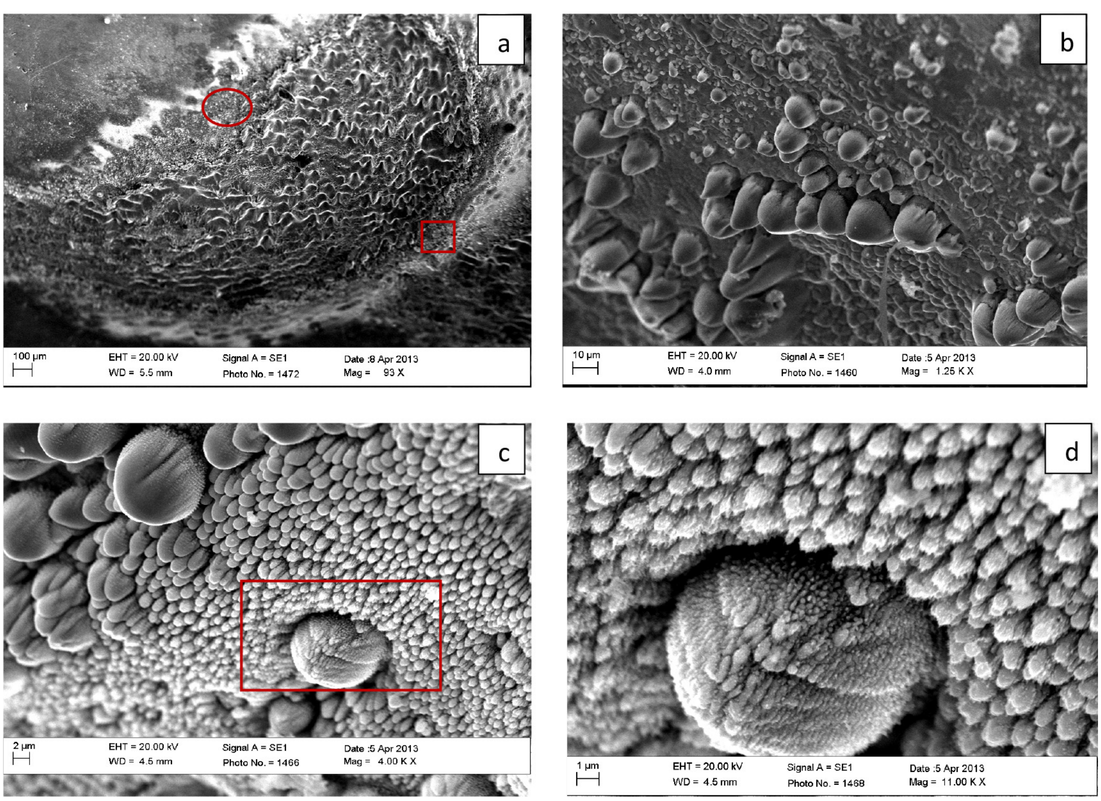

Fig. 1. Surface morphology of the laser treated region (a), laser treated spot (b), magnified image of the encircled region in image a. (c) Magnified SEM image of the square region in a. (d) Magnified SEM image of rectangular region in c.